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Effects of prolonged lack of amplification on speech-recognition performance: Preliminary findings

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Abstract—The purposes of this investigation were two-fold: 1) to prospectively investigate the effect of prolonged lack of binaural amplification in the unaided ears of adults with bilaterally symmetrical sensorineural hearing impairment (BSSHI) fitted monaurally; and, 2) to prospectively investigate the effects of amplification on speech-recognition performance in the aided ears of monaurally and binaurally fitted subjects. Subjects consisted of 19 monaurally aided adults, 28 binaurally aided adults, and 19 control adults. Both ears of the experimental subjects (binaurally and monaurally aided adults) had BSSHI. The speech measures included the W-22 CID suprathreshold speech-recognition test, nonsense syllable test, and speech-perception-in-noise test. Initial testing was done between 6 and 12 weeks following hearing-aid fitting. Retests were performed approximately 1 year following the initial test. The results revealed that the mean aided minus unaided ear score for the nonsense syllable and W-22 tests increased significantly from the initial test to retest, reflecting a slight improvement in speech performance in the aided ear and a slightly greater decrement in the unaided ear. The findings were interpreted with respect to the theories of auditory deprivation and acclimatization.

Key words: *acclimatization, auditory deprivation, binaural amplification, monaural amplification, nonsense syllable test, speech perception in noise, suprathreshold speech-recognition ability, word-recognition test.*

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INTRODUCTION

Silman, Gelfand, and Silverman (1) were the first to report the phenomenon of late-onset auditory deprivation in the unaided ears of monaurally fitted subjects with bilaterally symmetrical sensorineural hearing impairment (BSSHI). In their retrospective study of adult males with BSSHI consistent with a noise-induced origin, they reported that at approximately 4–5 years post hearing-aid fitting, the W-22 suprathreshold speech-recognition scores (SSRSs) decreased significantly under phones in the unaided, as compared with the aided ears of monaurally fitted subjects. An auditory-deprivation effect was absent in both ears of the binaurally fitted subjects.

Hood's findings supported the concept of auditory deprivation. He found that the SSRSs of the impaired ears (under phones) of persons with unilateral sensorineural hearing impairment due to Meniere's disease were lower than those of matched ears of persons with bilateral sensorineural hearing impairment due to Meniere's disease. Also, the SSRSs of the poorer ears were markedly poorer than those of the better ears of persons with only slightly asymmetrical, sensorineural hearing impairment due to Meniere's disease. Hood suggested that these findings resulted from "neglect" of the poorer ear because of dependence on the better ear (2,3).

Silman, Gelfand, and Silverman's (1) findings for the unaided ears of monaurally fitted subjects versus the aided ears of monaurally and binaurally fitted subjects were substantiated by the published retrospective and prospective findings of several investigators in this country (4,5,6,7,8), and abroad (9,10,11,12,13,14).

Gatehouse (11,12) evaluated the signal-to-noise (S/N) ratio for 50 percent performance using single words (taped, under phones) presented at 65, 70, 75, 80, 85, and 90 dB SPL in a noise background in a group of 24 monaurally fitted subjects seen at a mean time of 4.8 years post hearing-aid fitting. Although speech-recognition performance was unavailable for the subjects at the time of hearing-aid fitting, the pure-tone thresholds were symmetrical. The results revealed significantly higher S/N ratios in the unaided as compared with aided ears at the two highest presentation levels, consistent with the results of other investigations on auditory deprivation; reverse findings were obtained at the lowest presentation level. His finding raised the question of whether auditory deprivation is apparent for relatively low-intensity speech.

In more recent studies, Gatehouse (13,14) prospectively examined speech-recognition-in-noise ability in four subjects with BSSHI at the time of monaural hearing-aid fitting, and at weekly intervals of up to 12 weeks post-fitting, using the speech materials employed in his earlier studies. Significant decrements in speech-recognition-in-noise ability were observed when speech was presented under phones to the unaided ears of monaurally fitted subjects at a level equivalent to 65 dB SPL plus aid gain with a flat frequency response and at a level equivalent to 65 dB SPL with an aid-processed frequency response. Gatehouse reported that these findings could be interpreted as demonstrating the existence of auditory-deprivation effects occurring within 3 months post-fitting, at least for speech-in-noise materials. This finding of an auditory-deprivation effect at 65 dB SPL supports the concept of auditory deprivation being apparent for relatively low-intensity as well as high-intensity speech. Gatehouse also reported that speech-recognition-in-noise ability improved in the fitted ears of monaurally fitted subjects when speech was presented at 65 dB SPL through an aid-processed frequency response and at 65 dB SPL plus aid gain with an aid-processed frequency response (13,14). He interpreted this improvement in speech-recognition-in-noise in the fitted ear as manifesting the effects of acclimatization to the hearing aid and its frequency response.

The prospective studies that have been done on auditory deprivation are case studies. Therefore, prospective, larger sample studies are needed to investigate the phenomenon of auditory deprivation. Moreover, no published prospective research has investigated auditory deprivation in binaurally fitted subjects. The question must be raised as to whether acclimatization occurs in the binaurally fitted subjects as Gatehouse reported for the aided ears of monaurally fitted subjects (13,14).

Therefore, the purposes of this investigation were twofold: 1) to prospectively investigate the effect of prolonged lack of binaural amplification in the unaided ears of BSSHI adults fitted monaurally; and, 2) to prospectively investigate the effects of amplification on speech-recognition performance in the aided ears of monaurally and binaurally fitted subjects.

METHODS

Subjects

Subjects consisted of 19 monaurally aided adults (12 males and 7 females) aged 23 to 84 years (M = 65.8 years, SD = 13.5 years); 28 binaurally aided adults (21 males and 7 females) aged 40 to 80 years (M = 65.4 years, SD = 13.4 years); and 19 control adults (3 males and 16 females) aged 28 to 79 years (M = 62.0 years, SD = 14.0 years). Both ears of the experimental subjects (binaurally and monaurally aided adults) met the following criteria for BSSHI: 1) pure-tone average (PTA) (based on 500, 1000, and 2000 Hz) of at least 25 dB HL; 2) air-bone gaps not exceeding 10 dB at the audiometric frequencies between 500 and 4000 Hz and not exceeding 15 dB at 250 Hz; and, 3) acoustic-immittance results consistent with the absence of conductive or retrocochlear pathology. All of the experimental subjects had the following characteristics: 1) negative history of neurologic involvement; 2) interaural air-conduction threshold difference not exceeding 25 dB at each audiometric frequency; 3) interaural speech-recognition threshold (SRT) difference not exceeding 10 dB; and, 4) interaural SSRS difference not exceeding 20 percent.

Both ears of the control, normal-hearing subjects met the following criteria for inclusion in the study: 1) pure-tone, air-conduction thresholds no poorer than 25 dB HL at the audiometric frequencies between 250 and 2000 Hz, and no poorer than 35 dB HL at 4000 Hz; 2) SRT no poorer than 25 dB HL; 3) air-bone gaps not exceeding 10 dB at the audiometric frequencies between 500 and 4000 Hz, and not exceeding 15 dB at 250 Hz; and, 4) acoustic-immittance results consistent with the absence of conductive or retrocochlear pathology. All of the control subjects had a negative history of neurologic involvement.

Speech Materials

The speech materials consisted of: 1) the Auditec of St. Louis recording (male talker) of the 50-word, CID W-22 word lists; 2) a modified recording (male talker) of the speech perception in noise (SPIN) test (15); and, 3) a City University of New York recording (male talker) of the Nonsense Syllable Test (CUNY/NST) (16).

The "high predictability" (PH) sentences of the SPIN test were employed. These sentences were modified following Gelfand, Ross, and Miller (17) such that the average levels of the sentences fell within ± 1.5 dB of each other; several items were omitted because of possible distortions, leaving a total of 96 sentences. The noise was the 12-talker babble from the SPIN. The babble was dubbed onto the test tapes so that for each item the noise would come on first, nominally 1 second before the sentence began, and would remain on until about 1 second after the sentence ended.

The CUNY/NST consists of seven subtests, each of which contains seven to nine nonsense syllables of the CV or VC type. Each subtest employs a closed-set format and the response foils are essentially all of the remaining syllables within the subtest.

Procedure

All testing was done in a two-room audiometric suite meeting ANSI S3.1 (1977) standards for audiometric environments. All pure-tone, acoustic-reflex activating, and taped signals were routinely calibrated with a sound-level meter (B&K 4150) and coupler (NBS-9A).

Binaural amplification was recommended for all of the experimental subjects, who were first-time hearing-aid users. Those subjects who rejected binaural amplification in favor of monaural amplification because of financial or cosmetic reasons comprised the monaural group. Those subjects who accepted binaural amplification comprised the binaural group. Initial testing (Year 1 of this study) of the experimental subjects was done between 6 and 12 weeks post hearing-aid fitting. Retesting was done within 12 weeks following the annual anniversary of the initial test. All subjects who were retested indicated that they wore amplification for at least 4 hours per day.

A blind design was employed. That is, the interviewer who obtained the history and provided counseling at the initial and retest evaluations and the test administrator were not the same person for a given subject and the test administrator was not informed about the hearing-aid status (monaural versus binaural) of the experimental subjects.

The following tests were administered to each ear of each patient: 1) pure-tone, air-conduction testing at the octave frequencies of 250, 500, 1000, 2000, 4000, and 8000 Hz; 2) bone-conduction testing at the octave frequencies of 250, 500, 1000, 2000, and 4000 Hz; 3) SRT testing using taped spondaic W-1 words; 4) suprathreshold speech-recognition testing using taped CID W-22 monosyllabic PB words; 5) static-acoustic middle-ear admittance testing; 6) admittance-pressure function testing; 7) contralateral acoustic-reflex threshold testing using the 500-Hz, 1000-Hz, and 2000-Hz tonal activators and 226-Hz probe tone; 8) speech-recognition-in-noise threshold testing using the high PH sentences of the taped SPIN test; and, 9) taped NST.

The presentation level of the W-22, high PH SPIN sentences, and NST tests was 40 dB SL re: SRT whenever possible. It was reduced whenever necessary to accommodate the output limits of the audiometer or tolerance problems. For the SPIN materials, the up-down adaptive procedure (18,19) was applied to the intensity of the 12-talker babble to derive the S/N ratio corresponding to 50 percent sentence recognition.

The routine, audiologic tests preceded the speech-recognition tests. The order of the routine audiologic tests was as follows: 1) pure-tone, air-conduction thresholds; 2) pure-tone, bone-conduction thresholds; 3) SRT; 4) static-acoustic middle-ear admittance; 5) admittance-pressure function; and, 6) contralateral acoustic reflex threshold testing. The order of the W-22, SPIN, and NST tests was counterbalanced. At the initial test, the ear tested first was randomized. At the retest, the ear tested first was contralateral to the ear tested first at the initial test.

Scores consisted of individual ear scores, aided minus unaided ear scores for the monaurally aided group, right minus left ear scores for the binaurally aided and control groups, unaided plus aided ear scores for the monaurally aided group, and right plus left ear scores for the binaurally aided and control groups. A comparison using *t*-testing was made between the initial and retest scores in the monaurally aided, binaurally aided, and control groups.

RESULTS AND DISCUSSION

The means and standard deviations of the air-conduction thresholds and SRTs for the right and left ears of the binaurally aided and control groups and for the aided and unaided ears of the monaurally aided group at the initial test (Year 1) and retest (Year 2) are shown in **Table 1**. Inspection of **Table 1** reveals that the air-conduction thresholds and SRTs are symmetrical for the binaurally aided and control groups at the initial test and retest. Inspection of this table further indicates that the air-conduction thresholds and SRTs are slightly higher for the aided than unaided ears at the initial test and retest. Also, the SRTs and air-conduction thresholds of the monaurally aided and binaurally aided groups are essentially similar. There is essentially no change in the air-conduction thresholds or SRTs from the initial test to retest in the monaurally aided, binaurally aided, and control groups.

Table 1.
Means (M) and standard deviations (SD) of the air-conduction thresholds and SRTs for the right ears (RE) and left ears (LE) of the binaurally aided and control groups and for the aided (A) and unaided (UA) ears of the monaurally aided group at years 1 and 2.

	Frequency						
Group	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**SRT**
Monaural							
Yr 1 A M	28.8	30.3	37.4	49.7	60.5	70.8	33.4
UA M	20.3	25.0	30.5	40.5	55.0	64.2	28.4
Yr 1 A SD	14.2	11.8	9.8	10.6	15.0	20.4	11.2
UA SD	8.7	8.5	10.4	11.3	18.8	13.1	7.5
Yr 2 AM	25.6	30.8	38.4	50.5	60.8	72.4	35.9
UA M	23.2	26.3	32.6	43.4	57.9	65.4	28.9
Yr 2 A SD	12.9	11.9	10.4	11.7	16.1	19.2	11.1
UA SD	11.3	11.5	13.4	11.7	14.4	16.7	10.4
Binaural							
Yr 1 RE M	23.3	27.0	34.8	50.5	68.0	79.4	31.6
LE M	25.2	27.5	35.0	50.7	69.1	74.4	31.8
Yr 1 RE SD	13.7	14.1	14.9	13.2	14.2	15.1	12.6
LE SD	16.8	16.9	15.8	13.7	14.5	15.1	17.0
Yr 2 RE M	21.9	27.1	36.4	51.3	69.8	79.4	33.1
LE M	24.8	28.2	36.6	51.3	69.2	76.2	33.4
Yr 2 RE SD	12.3	13.9	15.6	13.6	14.3	14.0	13.2
LE SD	15.8	16.7	16.1	13.0	12.6	14.7	16.6
Control							
Yr 1 RE M	10.3	10.8	9.5	9.5	9.7	22.3	10.5
LE M	11.8	12.6	9.5	10.8	12.6	22.4	10.8
Yr 1 RE SD	8.6	7.9	7.8	9.6	10.6	16.7	10.1
LE SD	7.5	6.5	9.8	8.4	8.6	15.0	9.5
Yr 2 RE M	11.1	10.5	10.8	10.3	10.7	26.5	11.6
LE M	12.5	11.8	10.3	11.4	10.7	26.7	11.8
Yr 2 RE SD	6.3	10.5	10.4	10.5	9.0	16.8	8.5
LE SD	7.8	9.9	9.5	9.4	9.2	17.5	7.7

Table 2 shows the means and standard deviations of the W-22 SSRSs, SPIN S/N ratios, and NST SSRSs for each ear condition at the initial test (Year 1) and retest (Year 2) in the monaurally aided group. Inspection of the mean data in **Table 2** reveals that at the initial test, speech performance on the W-22, SPIN, and NST tests appeared to be slightly poorer in the aided than unaided ears of the monaurally aided group. This finding probably reflects the slightly poorer air-conduction thresholds and SRTs in the aided than unaided ears of the monaurally aided group.

Inspection of **Table 2** also shows that the mean aided minus unaided W-22 score significantly increased ($p < 0.05$) from the initial test to the retest, reflecting a slight improvement in speech performance in the aided ear and a slightly greater decrement in the unaided ear. Similarly, the mean aided minus unaided NST score significantly in-

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Table 2.
Means (M) and standard deviations (SD) of the W-22 suprathreshold speech-recognition scores, SPIN S/N ratios, and NST suprathreshold speech-recognition scores for each ear condition at years 1 and 2 in the monaurally aided group.

	Ear Condition			
Test	**Aided**	**Unaided**	**Aid-Unaid**	**Aid + Unaid**
W-22				
Year 1 M	79.37	84.00	−4.63	163.37
Year 1 SD	12.76	12.54	13.48	20.84
Year 1 N	19	19	19	19
Year 2 M	82.00	77.47	4.53	159.47
Year 2 SD	9.55	15.60	12.77	21.90
Year 2 N	19	19	19	19
SPIN				
Year 1 M	20.35	14.41	5.94	34.77
Year 1 SD	14.40	15.38	12.55	26.21
Year 1 N	17	17	17	17
Year 2 M	19.59	16.77	2.82	36.35
Year 2 SD	11.23	9.55	8.84	18.32
Year 2 N	17	17	17	17
NST				
Year 1 M	0.5975	0.6958	−0.0984	1.2933
Year 1 SD	0.1547	0.1120	0.1041	0.2417
Year 1 N	17	17	17	17
Year 2 M	0.6622	0.5989	0.0633	1.2612
Year 2 SD	0.1310	0.1756	0.2280	0.2035
Year 2 N	17	17	17	17

creased ($p<0.05$) from the initial test to the retest, reflecting a slight improvement in the aided ear and a slightly greater decrement in the unaided ear.

The finding that the W-22 and NST mean aided minus unaided ear scores were significantly increased at the retest as compared with the test was substantiated by the following trends: 1) the retest mean W-22 and NST scores were slightly higher than the test mean scores in the aided ears; 2) the retest mean W-22 and NST scores were slightly lower than the test mean scores in the unaided ears; and, 3) the retest aided plus unaided mean W-22 and NST scores were slightly lower than the test scores.

These findings, which show a trend toward improvement in the aided ear, are consistent with the findings reported by Gatehouse (13,14). Gatehouse has interpreted improvement in the aided ear as evidence of acclimatization to the hearing aid. These findings also show a trend toward decrement in the unaided ear and are consistent with the finding of auditory deprivation in the unaided ear that was reported by several investigators (1,4,5,6,7,8,9,10,11,12,13,14). The trend toward improvement in the aided ear from test to retest and the trend toward a decrement in the unaided ear from test to retest yielded an aided minus unaided ear score that was significantly greater at the retest than test.

Although the mean aided minus unaided ear SPIN score at the retest was not significantly different from that at the initial test, inspection of the mean data in **Table 2** shows that speech performance in noise worsened from the test to retest in the unaided ear and improved from test to retest in the aided ear. Again, the decrement in the unaided ear appeared greater than the improvement in the aided ear. These findings were substantiated by the trend toward a decrease in the mean aided minus unaided ear SPIN score and in the mean aided plus unaided ear SPIN score.

Based on finding of a significant difference in the aided minus unaided ear scores between the retest and initial test for the W-22 and NST but not SPIN measures, it appears that the W-22 and NST measures are more sensitive than the SPIN measure to the effects of auditory deprivation in the unaided ear and acclimatization in the aided ear. Perhaps a significant difference between the retest and test mean SPIN scores will develop over time. Interestingly, Gatehouse (13,14) observed significant findings for the unaided and aided ears with his speech-in-noise test in the monaurally aided group at the retest performed only 12 weeks post hearing-aid fitting. In contrast, the speech-in-noise test employed in this study failed to show significant auditory deprivation or acclimatization findings at the retest performed one year post hearing-aid fitting. One possible explanation of this discrepant finding is related to the sensitivity of the speech measure and the procedure for measuring the S/N ratio. The speech-in-noise measure employed by Gatehouse (13,14) was a forced-choice word identification test based on the rhyme test principle. In contrast, the SPIN test employed by the present investigators is an open-set sentence test. Gatehouse determined the S/N ratio for 70.7 percent correct identification, whereas the present investigators determined the S/N ratio for 50 percent correct identification. Thus, the speech-in-noise measure employed by Gatehouse was more of a suprathreshold test than the SPIN measure; perhaps the effects of auditory deprivation and acclimatization are more apparent on suprathreshold than on threshold tests.

Table 3 shows the means and standard deviations of the W-22 SSRSs, SPIN S/N ratios, and NST SSRSs for each ear condition at the initial test and retest in the binaurally aided group. The results of *t*-testing revealed that the mean retest score did not differ significantly from the mean retest score under any of the ear conditions in the binaurally aided group. This is consistent with the finding of absence of auditory deprivation in binaurally aided persons reported by Silman, Gelfand, and Silverman (1) and others. Inspection of **Table 3** reveals a trend toward improvement at the retest as compared with the initial test for most of the ear conditions and speech measures.

Table 4 shows the means and standard deviations of W-22 SSRSs, SPIN S/N ratios, and NST

Table 3.
Means (M) and standard deviations (SD) of the W-22 suprathreshold speech-recognition scores, SPIN S/N ratios, and NST suprathreshold speech-recognition scores for each ear condition at years 1 and 2 in the binaurally aided group.

	Ear Condition			
Test	**Right**	**Left**	**Right-Left**	**Right + Left**
W-22				
Year 1 M	77.43	76.07	1.36	153.50
Year 1 SD	13.83	18.75	14.38	29.11
Year 1 N	28	28	28	28
Year 2 M	81.70	78.96	2.74	160.67
Year 2 SD	15.93	15.97	12.00	29.00
Year 2 N	28	28	28	28
SPIN				
Year 1 M	16.09	14.64	1.46	30.73
Year 1 SD	10.57	11.30	9.46	19.28
Year 1 N	24	24	24	24
Year 2 M	15.33	14.17	1.17	29.50
Year 2 SD	12.74	10.84	9.87	21.05
Year 2 N	24	24	24	24
NST				
Year 1 M	0.6404	0.6150	0.0254	1.2554
Year 1 SD	0.1329	0.1323	0.1197	0.2317
Year 1 N	25	25	25	25
Year 2 M	0.6642	0.6143	0.0499	1.2785
Year 2 SD	0.1329	0.1342	0.1168	0.2354
Year 2 N	25	25	25	25

Table 4.
Means (M) and standard deviations (SD) of the W-22 suprathreshold speech-recognition scores, SPIN S/N ratios, and NST suprathreshold speech-recognition scores for each ear condition at years 1 and 2 in the control group.

	Ear condition			
Test	**Right**	**Left**	**Right-Left**	**Right + Left**
W-22				
Year 1 M	96.30	97.30	− 1.00	193.2
Year 1 SD	3.73	3.06	2.87	6.27
Year 1 N	20	20	20	20
Year 2 M	97.68	95.26	2.63	193.0
Year 2 SD	2.77	4.82	5.08	5.98
Year 2 N	20	20	20	20
SPIN				
Year 1 M	1.65	1.70	0.15	3.35
Year 1 SD	2.50	1.50	1.90	3.65
Year 1 N	20	20	20	20
Year 2 M	1.05	1.25	0.00	2.30
Year 2 SD	1.82	1.97	1.84	3.26
Year 2 N	20	20	20	20
NST				
Year 1 M	0.8235	0.8246	− 0.0003	1.6577
Year 1 SD	0.0811	0.0570	0.0702	0.1069
Year 1 N	20	20	20	20
Year 2 M	0.8437	0.8094	0.0344	1.6553
Year 2 SD	0.0748	0.0769	0.0998	0.1145
Year 2 N	20	20	20	20

SSRSs for each ear condition at the initial test and retest in the control group. The results of *t*-testing revealed that, similar to the results for the binaurally aided group, the mean retest score did not differ significantly from the mean test score under any of the ear conditions and speech measures. This is consistent with the expected finding of an absence of auditory deprivation and acclimatization in normal-hearing persons. Inspection of **Table 4** reveals the absence of any trends in the retest scores as compared with the initial test scores for any of the ear conditions and speech measures.

The decrement in the unaided ear appeared to be of greater magnitude than the improvement in the aided ear in the monaurally aided group. It is likely that more time will be required for a significant acclimatization effect to emerge in the aided ears of both the monaurally and binaurally aided groups than for a significant auditory-deprivation effect to emerge in the unaided ears of the monaurally aided group.

The subjects in this study are being followed over a 3-year period. Based on the findings reported here, it is hypothesized that speech-recognition performance in the unaided ear will decrease significantly and speech-recognition performance in the aided ear will improve significantly at future retest as compared with the initial test on all of the speech measures. The findings of this preliminary report supports the use of binaural amplification in persons with BSSHI.

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